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Cost and Quality Planning for Large NASA Programs

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The Software Cost and Quality Engineering methodology developed over the last two decades at IBM Federal Sector Division (FSD) in Houston is used to plan the NASA Space Station Data Management System (DMS). An ongoing project to capture this methodology, which is built on a foundation of experiences and "lessons learned," has resulted in the development of a PC-based tool that integrates cost and quality forecasting methodologies and data in a consistent manner. This tool, Software Cost and Quality Engineering Starter Set (SCQESS), is being employed to assist in the DMS costing exercises. At the same time, DMS planning serves as a forcing function and provides a platform for the continuing, iterative development, calibration, and validation and verification of SCQESS. The data that forms the cost and quality engineering database is derived from more than 17 years of development of NASA Space Shuttle software, ranging from low criticality, low complexity support tools to highly complex and highly critical onboard software.

INTRODUCTION

Software cost and quality engineering is the systematic approach to the estimation, measurement, and control of software costs and quality on a project. This discipline provides the vital link between the concepts of economic analysis and the methodology of software engineering. The tasks involved in software cost and quality engineering are complex, and individuals with the knowledge and skill required are scarce. The accuracy and consistency of the results are often questionable. There is a definite need for tools to enable analysis by managers and planners who are not experts and to improve the results.

There are many instances in planning software development activities when a quick and easy to use cost and quality estimating tool would be of value. These include management consulting, proposal generation, and analysis of existing programs for problem correction or assurance. There is little time to learn a complex tool or to digest introductory user information. SCQESS requires no set-up, has a selectable demonstration, direct access to the tool functions, and contains examples of varied applications.

SCQESS resides on a tool sharing disk which is available to all company sites. The user has the option of viewing a demonstration program to illustrate the cost and quality estimation process. SCQESS includes a Lotus-based cost and quality estimation spreadsheet. The spreadsheet includes cost and quality models which are based on historical data and various criticality levels. If different models are required, the existing models can be easily modified. An example Lotus spreadsheet illustrates a completed estimation. This spreadsheet can be modified or a blank file is supplied if the work is entirely new. The tool can handle estimates involving many languages including Ada and can also be used for estimating reused elements.

Once the basic cost and quality estimates are completed, the user executes a Rayleigh Curve program to phase the estimates over time. A Rayleigh curve is a plot of a mathematical function which describes life cycle phenomena. A Rayleigh curve indicates whether the slope of the staffing curve is too steep or whether the error density of the project is too great at certain points in the process.

The cost and quality estimate can then be quickly modified to determine variance of results based on changes in assumptions. The cost and quality estimates support the strength of the plan being generated. The estimates can be used to analyze risk and mitigation plans. Examples of actual project cost and quality reports are available to the user. These examples include a project involving Ada, reuse and commercial elements; a project involving translation of code from one machine architecture to another; and a transaction oriented commercial system. The spreadsheets and the Rayleigh curves are included in the report.

Software Life Cycle Costing and Quality Estimation Methodology

Past experience in managing large software projects such as Space Shuttle Onboard Software illustrates that accurate cost and quality estimates based on reliable historical data are essential to software planning. FSD Houston has collected extensive data from NASA and other software development projects over the last 17 years. This data includes source lines of code, productivity, error rates, computer usage, etc. for more than 250 projects. Historical data supports initial estimation of project size and estimation of effort from that size. The standard Rayleigh curve model converts estimated labor to a schedule and staffing profile - the elements of a cost plan. It also projects error estimates across the schedule to generate a quality plan.

The widely used Rayleigh curve models the typical build-up of staff and errors during the requirements and design phases, the peak for implementation, and the tail-off during the testing phase. The staffing schedule for an ideal project approximates a Rayleigh curve. During sustaining engineering, a minimum level of critical skills is required for effective maintenance. This steady-state staffing level forms the support line. It includes critical skills for requirements, design, implementation, testing, and management. The support line is a function of system size and productivity as well as unique skill requirements specific to the software being maintained.

The areas below the support line and above the maintenance tail of the Rayleigh curve is available for new development work. Sustaining engineering operational increment also corresponds to a Rayleigh curve. Each sustaining engineering effort can be modeled as the sum of a sequence of such curves. The sizing and scheduling of new development activities should be planned to provide a stable level of effort. Software maintenance which handles Discrepancy Reports can continue at a lower support level.

Historical project data supports software size, labor, and quality estimation. The Lotus-based Matrix Method function distributes the effort and errors over organizational elements. The Rayleigh Curve function generates a staffing and error discovery profile over time. Special models are available in other packages to adjust estimates involving expert systems, reusable software, reconfiguration, quality tracking, and maintenance.

Planning the Space Station DMS Utilizing SCQESS

SCQESS has been used to assist in the costing of the Space Station Data Management System (DMS), a complex software system involving a distributed environment with multiple languages and applications. The DMS for Space Station is also affected by the requirements for long lifetime, permanent operations, remote integration, and phased technology insertion of productivity tools, applications, expert systems, etc. Major cost and quality drivers include the large size and diversity of the software, complexity, development support environment, off-the-shelf and reusable software, and criticality, which varies from one module to another. An example of the type of results — at the end of the intermediate step of development cost and quality estimation — obtained with SCQESS for the DMS planning is included in the presentation.

Summary/Conclusions

The software cost and quality engineering methodology employed at IBM FSD Houston has been captured and integrated into a prototype tool, SCQESS. This PC-based tool integrates cost and quality planning methodology and data.

SCQESS has been employed to assist in the cost and quality planning of the Space Station DMS (Data Management System). It is providing a standardized approach for the DMS planning, which involves several individuals. It has made the process more efficient and has allowed a consistent approach to planning. The automation and captured methodology has established the foundation and mechanism enabling the continuing calibration and improvement in accuracy and consistency for Space Station DMS costing.

VIEWGRAPH MATERIALS

FOR THE

K. RONE PRESENTATION

6269-0

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Keys to Customer Satisfaction

- Compliant Product
- Within Budget
- On Time
- Appropriate Quality Level

Concurrently

Consistently

Approach

```
 ____________     ____________     ____________     ____________     ____________     ____________
|            |   |            |   |            |   |            |   |            |   |            |
|            |   |            |   |            |   |            |   |            |   |            |
| Initiation |___| Measurement|___|  Modeling  |___| Prediction |___|  Control   |___| Improvement|
|            |   |            |   |            |   |            |   |            |   |            |
|____________|   |____________|   |____________|   |____________|   |____________|   |____________|
```

Keys \ Steps	Initiation	Measurement	Modeling	Prediction	Control	Improvement
Product	• Process • Interim Product • Procedure Order • Tailoring Mechanism	• Size • Process Proficiency	• Process Models	• Process Tailoring	• Control Points	• Modify Process • Modify Ordering • Automation
Cost		• Function Driven Cost • Schedule Driven Cost • Complexity • Criticality	• Factor Models • % Models • Phasing	• Calibrate To Process • Function Driven	• Cost Management	• Modify Cost Models
Schedule		• Process Elapsed Time • Process Order	• Schedule Rules Of Thumb	• Phased Cost and Errors	• Schedule Management	• Modify Schedule Rules of Thumb
Quality		• Inspection Errors • Process Errors • Product Errors • Total Errors	• Life Cycle Errors • % Models • Phasing	• Calibrate To Process • Function Driven • Cost Driven	• Quality Management	• Modify Quality Models

MODEL RECONCILIATION

- o ALT (EARLY MODEL)
  - PROJECTED = 10429 MM
  - DEVELOPMENT PART OF ALT = 9403 MM ACTUALS
  - ERROR IS 1026 MM OR 11% HIGH

- o STS-1 (MIDDLE MODEL)
  - PROJECTED = 8905 MM
  - DEVELOPMENT PART OF STS-1 = 9521 MM ACTUALS
  - ERROR IS 616 MM OR 6% LOW

- o STS-2 THRU STS-5 (MIDDLE MODEL)
  - PROJECTED = 5864 MM
  - DEVELOPMENT PART OF STS-2 THRU STS-5 = 5994 MM ACTUALS
  - ERROR IS 130 MM OR 2% LOW

- o TOTAL
  - TOTAL PROJECTED = 10429 + 8905 + 5864 = 25198 MM
  - TOTAL ACTUALS = 9403 + 9521 + 5994 = 24918 MM
  - ERROR IS 280 MM OR 1% HIGH

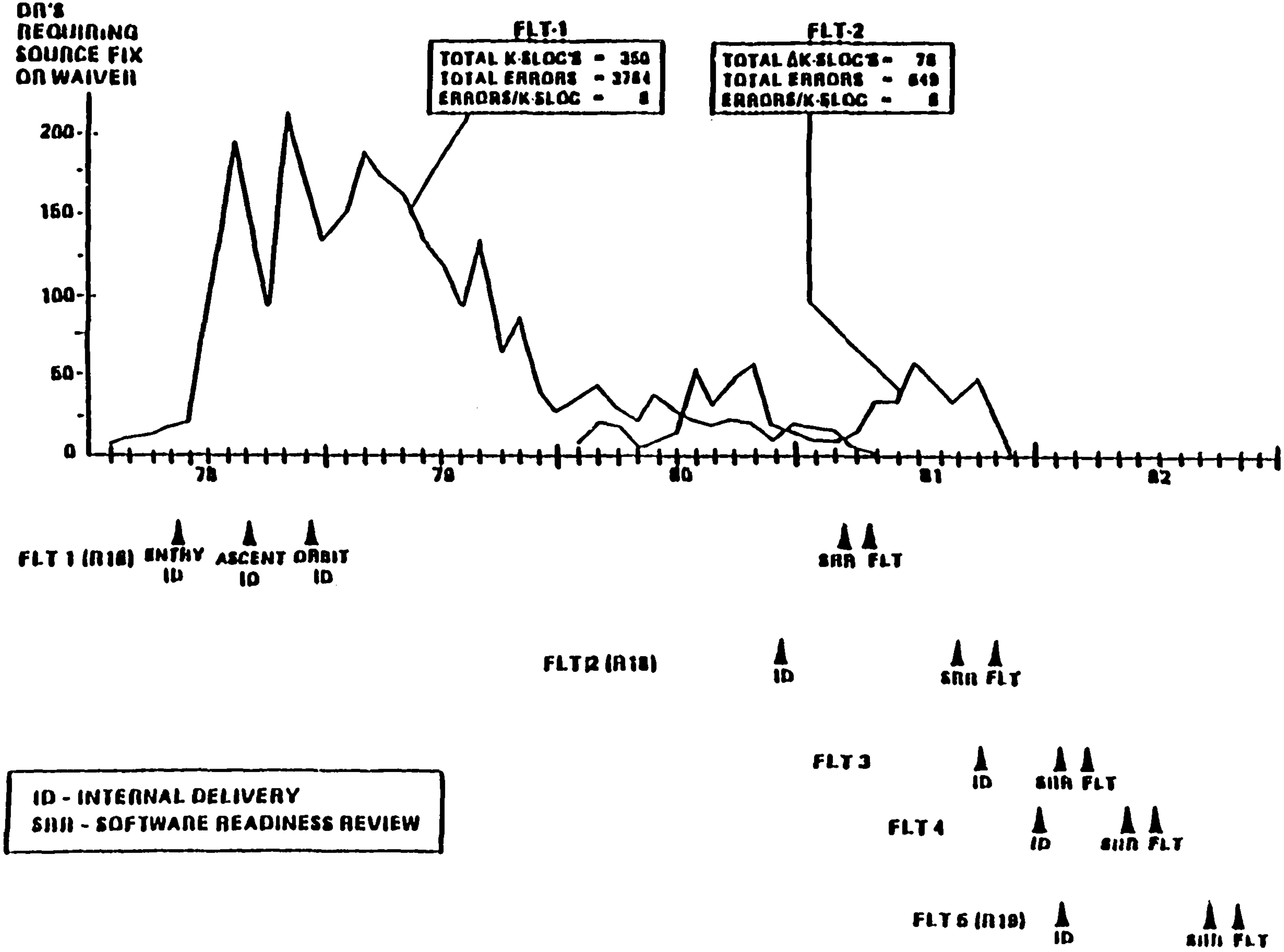
- o STS-1 THRU STS-5 (MIDDLE MODEL)
  - TOTAL STS-1 THRU STS-5 PROJECTED = 8905 + 5864 = 14769 MM
  - TOTAL ACTUALS = 9521 + 5994 = 15515 MM
  - ERROR IS 746 MM OR 5%

MODEL RECONCILIATION

- SDL
  - (900,000/230) 1.4 = 5478 MM
  - SDL ACTUALS = 5730 MM
  - ERROR IS 252 MM OR 4% LOW

- SPF
  - ((250,000/230) + (315,000/250) + (385,000/475)) 1.4 = 4421 MM
  - SPF ACTUALS = 4033
  - ERROR IS 388 MM OR 10% HIGH

- TOTAL
  - TOTAL PROJECTED = 5478 + 4421 = 9899 MM
  - TOTAL ACTUALS = 5730 + 4033 = 9763 MM
  - ERROR IS 136 MM OR 1% HIGH


DR'S REQUIRING SOURCE FIX OR WAIVER
FLT-1
TOTAL K-SLOC'S = 350
TOTAL ERRORS = 3784
ERRORS/K-SLOC = 8
FLT-2
TOTAL ΔK-SLOC'S = 78
TOTAL ERRORS = 649
ERRORS/K-SLOC = 8
200
150
100
50
0
78
79
80
81
82
FLT 1 (R18)
ENTRY ID
ASCENT ID
ORBIT ID
SRR
FLT
FLT 2 (R18)
ID
SRR
FLT
FLT 3
ID
SRR
FLT
FLT 4
ID
SRR
FLT
FLT 5 (R19)
ID
SRR
FLT
ID - INTERNAL DELIVERY
SRR - SOFTWARE READINESS REVIEW

ERROR DISCOVERY PROFILE FOR PROJECT 04-13-1990

SOFTWARE DEVELOPMENT ACTIVITY	ERRORS PER KSLOC USER PROVIDED	PROGRAM ESTI
HIGH LEVEL DESIGN INSPECTION	0.11	1.0062
LOW LEVEL DESIGN INSPECTION	4.20	3.1667
CODE INSPECTION	6.80	6.9371
UNIT TEST	—	3.721
INTEGRATION TEST	—	2.011
SYSTEM TEST	—	0.854
LATENT ERROR	—	0.598

THE PATTERN PROJECTED IS PATTERN NUMBER: 14
THE ESTIMATED TOTAL LIFETIME ERROR CONTENT IS: 18.29

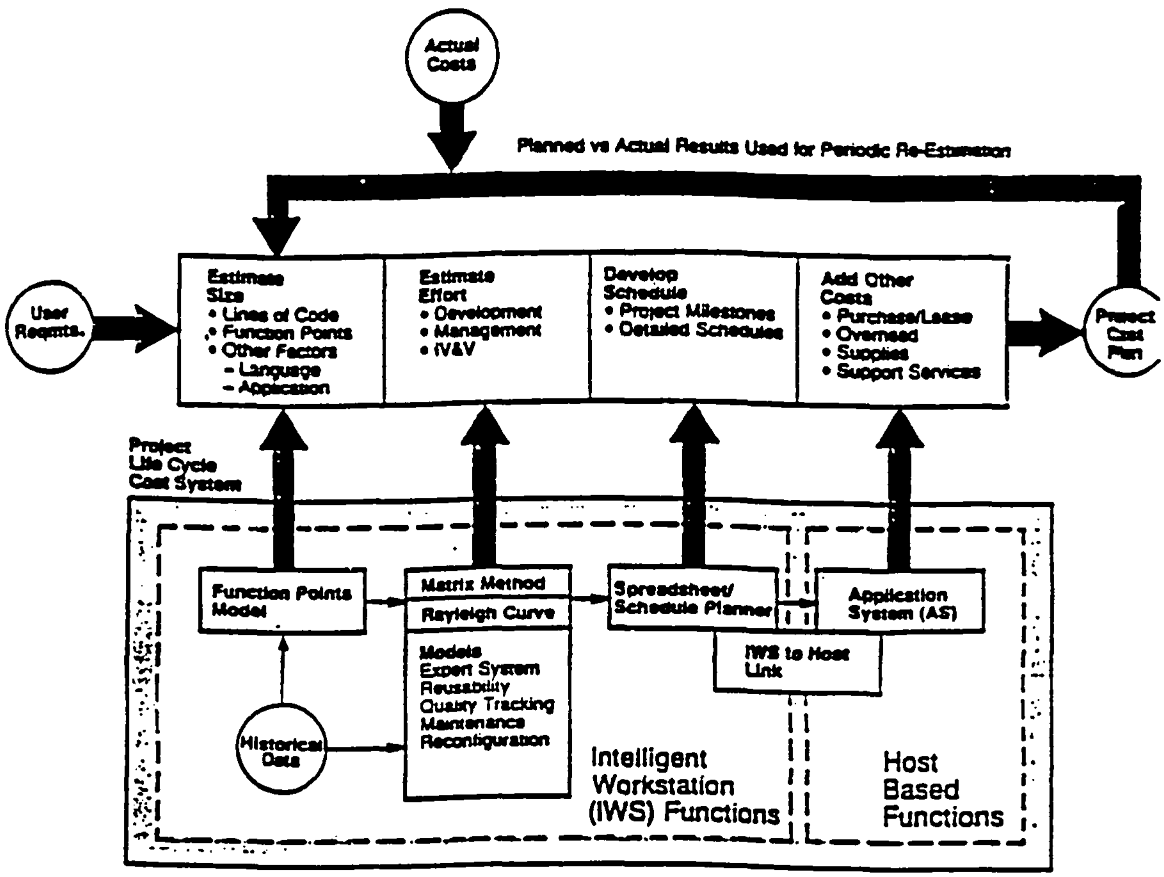
PRESS:ENTER FOR MENU SCREEN ;PrtSc & Shift TO PRINT SCREEN: Y TO GRAPH DATA

PROJECTION COMPARISON

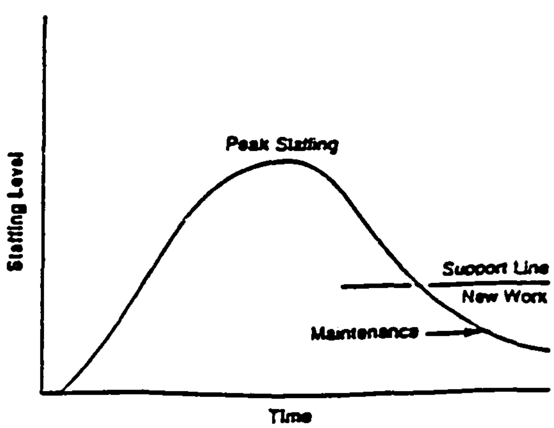
	STEER	ACTUAL
• TOTAL RELEASE		
- TOTAL INSERTED ERROR RATE	18.3	13.3
- PRODUCT ERROR RATE	.6	1.0
• HOST		
- TOTAL INSERTED ERROR RATE	13.0	8.5
- PRODUCT ERROR RATE	.4	.3
• W/S		
- TOTAL INSERTED ERROR RATE	35.1	28.8
- PRODUCT ERROR RATE	1.1	3.2

PROJECTION COMPARISON
(INCLUDING PROCESS DATA)

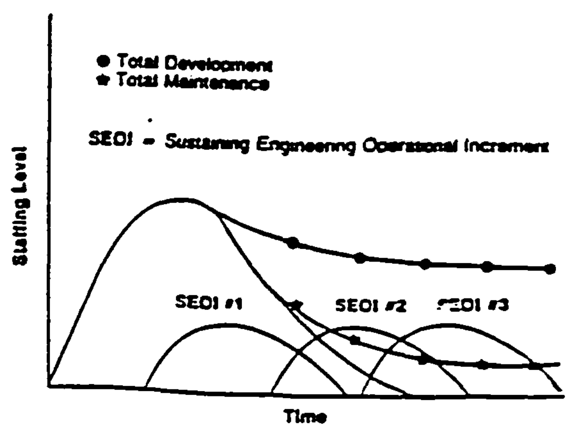
	STEER	ACTUAL
• TOTAL RELEASE		
- TOTAL INSERTED ERROR RATE	13.54	13.28
- PRODUCT ERROR RATE	1.25	1.0
• HOST		
- TOTAL INSERTED ERROR RATE	8.47	8.52
- PRODUCT ERROR RATE	.28	.33
• W/S		
- TOTAL INSERTED ERROR RATE	28.28	28.82
- PRODUCT ERROR RATE	2.62	3.16



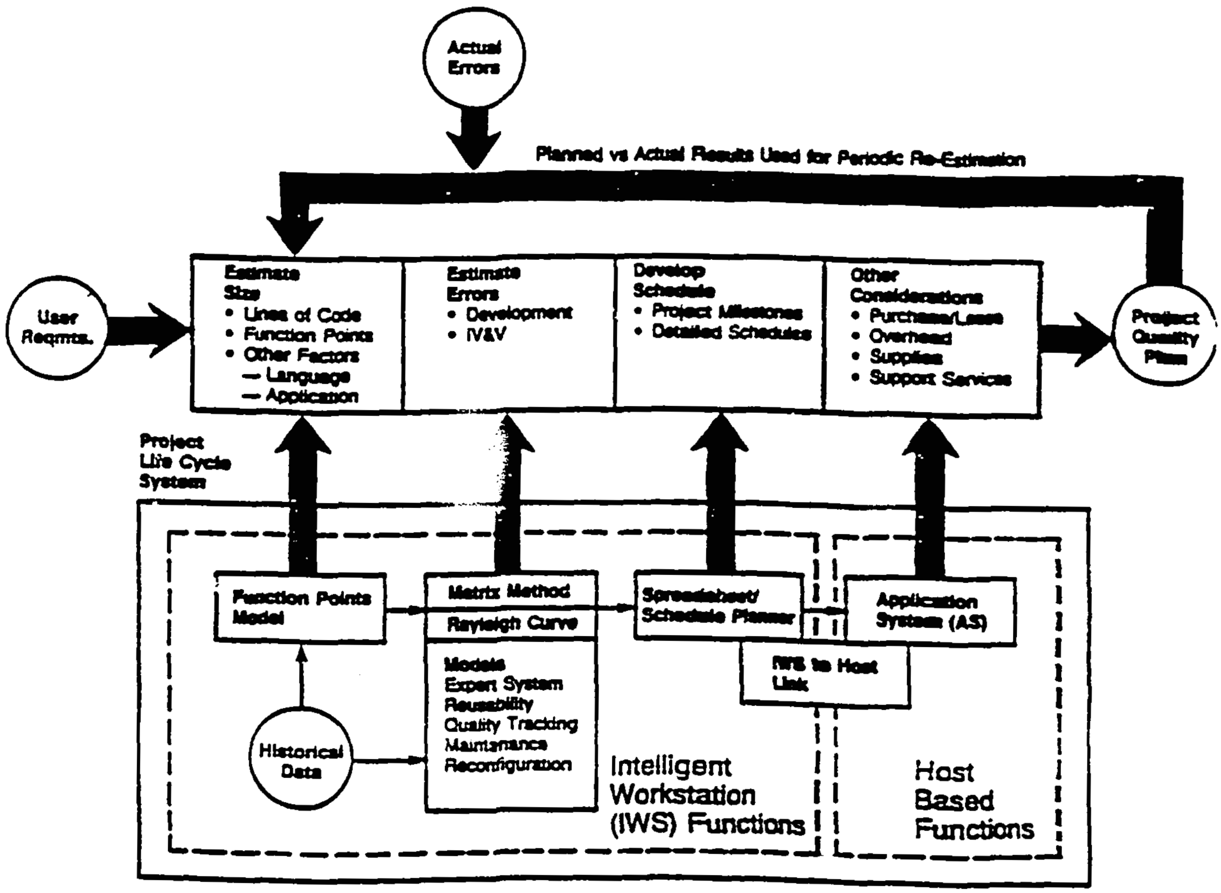
Staffing over a software development project is modeled using a Rayleigh Curve.



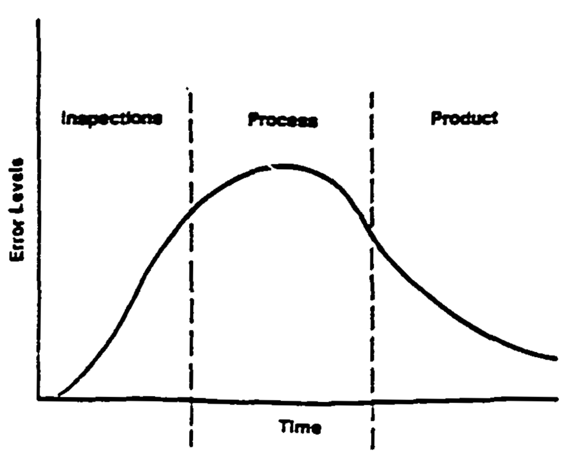
Software sustaining engineering is modeled as a sequence of overlapping Rayleigh Curves.



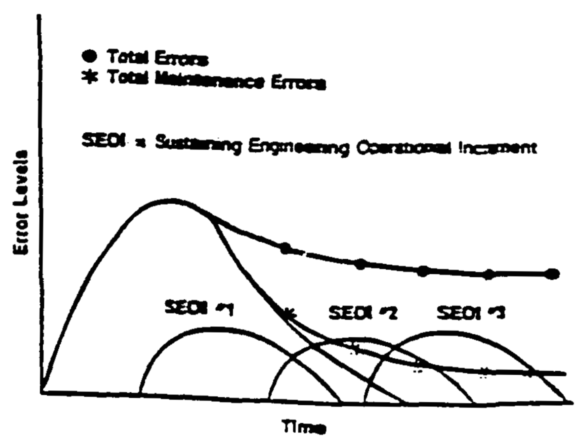
Software Life Cycle Quality Management

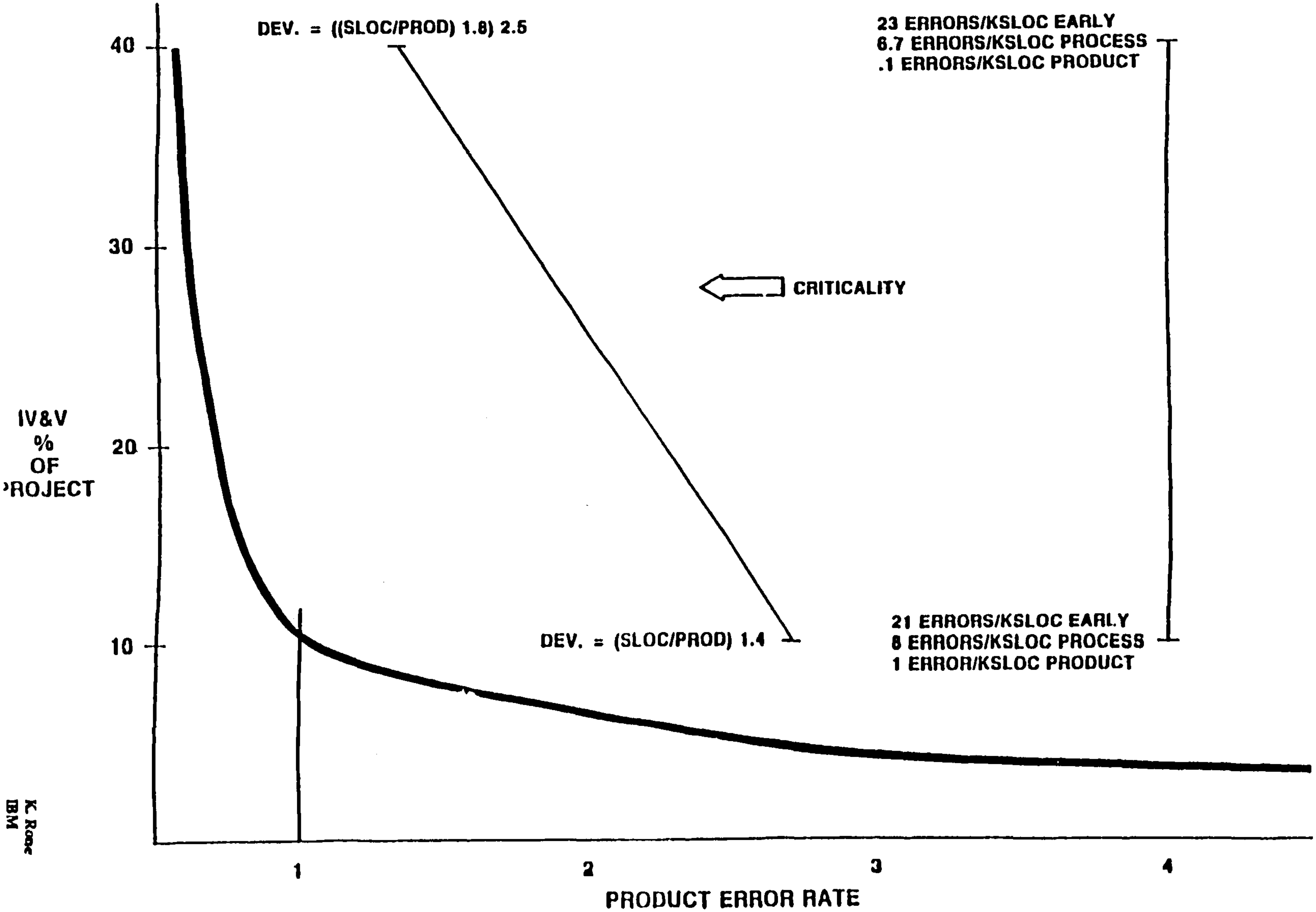


Error discovery over a software development project is modeled using a Rayleigh Curve.

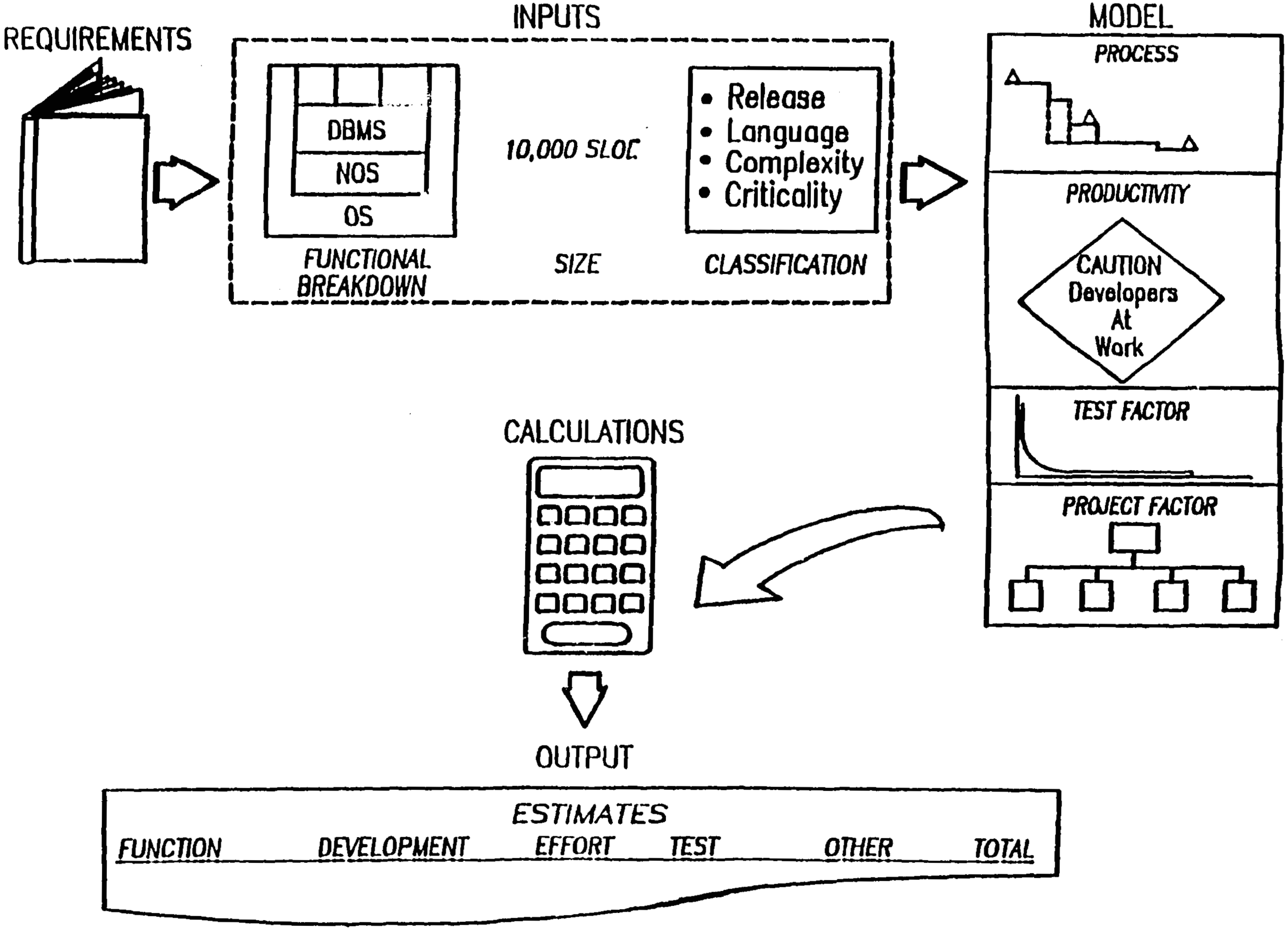


Software sustaining engineering is modeled as a sequence of overlapping Raleigh Curves.




DEV. = ((SLOC/PROD) 1.8) 2.5
23 ERRORS/KSLOC EARLY
6.7 ERRORS/KSLOC PROCESS
.1 ERRORS/KSLOC PRODUCT
CRITICALITY
IV&V % OF PROJECT
40
30
20
10
DEV. = (SLOC/PROD) 1.4
21 ERRORS/KSLOC EARLY
8 ERRORS/KSLOC PROCESS
1 ERROR/KSLOC PRODUCT
1
2
3
4
PRODUCT ERROR RATE

SOFTWARE COSTING METHODOLOGY



NOS

AREA	NEW (SLOC)	COTS (SLOC)	REL.	CRIT.	LANG.	COMP.	DEV.	VERIF.	INDIRECT	TOTAL
NETWORK LAYERS	3200		2	SC	ADA	C	24.6	19.7	66.5	110.8
TRANSPORT LAYERS	3900		2	SC	ADA	C	30	24	81	135
SESSION LAYERS	5700		2	SC	ADA	C	43.8	35	118.2	197
PRESENTATION LAYERS										
APPLICATION LAYERS										
CASE	1800		2	SC	ADA	C	13.8	11	37.2	62
RJE	5000		2	SC	ADA	C	38.5	30.8	104	173.3
DIRECT ACCESS	2000		3	SC	ADA	C	13.3	10.6	35.9	59.8
NETWORK MGMT.	16000		3	SC	ADA	C	106.7	85.4	288.2	480.3
APPLICATION SERV.	2000		2	SC	ADA	C	15.4	12.3	41.6	69.3
TOTALS:	39600						286.1	228.8	772.6	1287.5

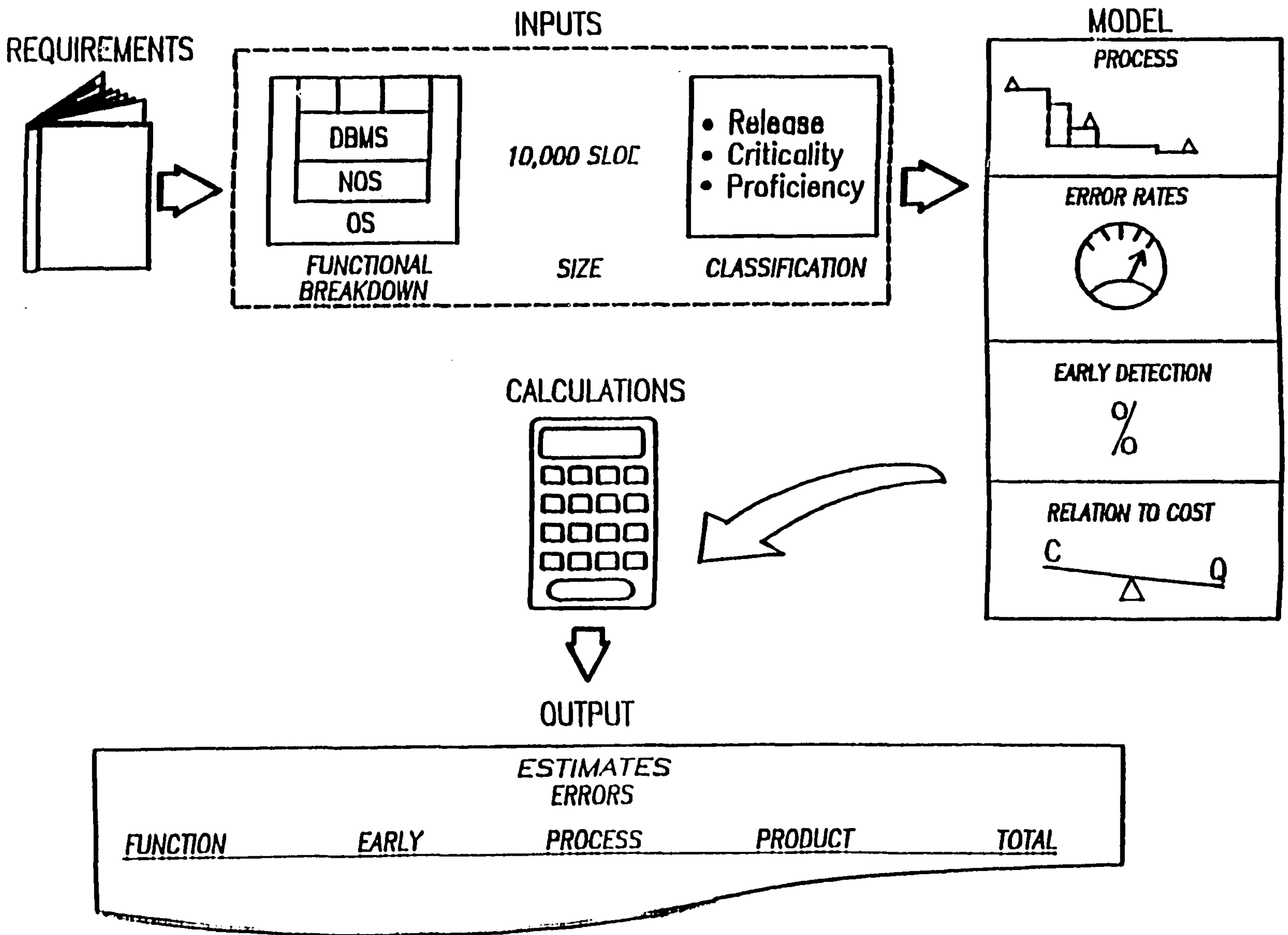
OS

AREA	NEW (SLOC)	COTS (SLOC)	REL.	CRIT.	LANG.	COMP.	DEV.	VERIF.	INDIRECT	TOTAL
KERNAL										
TASK		2300	1	SC	ASSM	L	1	0.8	2.7	4.5
MEMORY MGMT.		5400	1	SC	ASSM	L	2.3	1.8	6.2	10.3
INTERUPT		6500	1	SC	ASSM	L	2.8	2.2	7.5	12.5
I/O MGMT.		5000	1	SC	ASSM	L	2.2	1.8	6	10
RESOURCE MGMT.		3000	1	SC	ASSM	L	1.3	1	3.5	5.8
INTER PROC. COMM.		1000	1	SC	ASSM	L	0.4	0.3	1.1	1.8
FAULT MGMT.		1000	1	SC	ASSM	L	0.4	0.3	1.1	1.8
MPAC UNIQUE		16700	1	SC	ASSM	L	7.3	5.8	19.7	32.8
MPAC UNIQUE	2200		1	SC	ADA	C	22	17.6	59.4	99
SDP UNIQUE	1800		1	SC	ADA	C	18	14.4	48.6	81
NIU UNIQUE	1800		1	SC	ADA	C	18	14.4	48.6	81
EDP UNIQUE	1800		1	SC	ADA	C	18	14.4	48.6	81
TOTALS:	7600	40900					93.7	74.8	253	421.5

SUMMARY CHART

AREA	NEW (SLOC)	COTS (SLOC)	REL.	CRIT.	LANG.	COMP.	DEV.	VERIF.	INDIRECT	TOTAL
NOS	39600						286.1	228.8	772.6	1287.5
OS	7600	40900					93.7	74.8	253	421.5
ADA RTE	41500						383.2	306.6	1034.8	1724.6
STANDARD SERVICES	93100						606.9	390.7	1248.2	2245.8
DMS SYSTEM MANAGEMENT	20700						119.9	73.1	229.9	422.9
DATA STORAGE & RETRIEVAL	26000	50000					196.2	109.3	333.2	638.7
USE	223500						1403.5	452.6	1449.1	3325.2
USE CONTINUED	144000	170000					521.5	52.3	172.2	746
OMA	42000						280	28	92.4	400.4
TOTALS:	638000	260900					3891	1716.2	5605.4	11222.6

SOFTWARE QUALITY FORECASTING



NOS

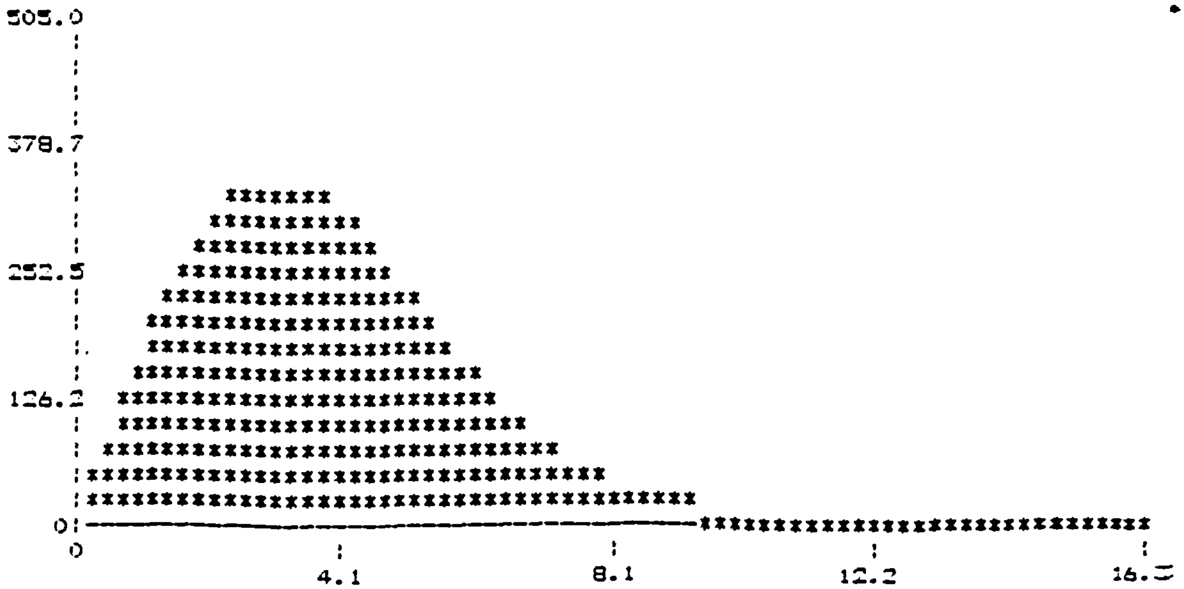
AREA	NEW (SLOC)	COTS (SLOC)	REL.	CRIT.	PROJECT PROF.	DVPMENT PROF.	EARLY	PROCESS	PRODUCT	TOTAL
NETWORK LAYERS	3200		2	SC	GD	AV	62.4	33.3	0.3	96.0
TRANSPORT LAYERS	3900		2	SC	GD	AV	76.1	40.6	0.4	117.0
SESSION LAYERS	5700		2	SC	GD	AV	111.2	59.3	0.6	171.0
PRESENTATION LAYERS										
APPLICATION LAYERS										
CASE	1800		2	SC	GD	AV	35.1	18.7	0.2	54.0
RJE.	5000		2	SC	GD	AV	97.5	52.0	0.5	150.0
DIRECT ACCESS	2000		3	SC	GD	AV	42.0	17.8	0.2	60.0
NETWORK MGMT.	16000		3	SC	GD	AV	336.0	142.4	1.6	480.0
APPLICATION SERV.	2000		2	SC	GD	AV	39.0	20.8	0.2	60.0
TOTALS:	39600						799.2	384.8	4.0	1188.0

OS

AREA	NEW (SLOC)	COTS (SLOC)	REL.	CRIT.	PROJECT PROF.	DVPMENT PROF.	EARLY	PROCESS	PRODUCT	TOTAL
KERNAL										
TASK		2300	1	SC	GD	AV	4.1	2.7	0.0	6.8
MEMORY MGMT.		5400	1	SC	GD	AV	9.7	6.4	0.1	16.2
INTERUPT		6500	1	SC	GD	AV	11.7	7.7	0.1	19.5
I/O MGMT.		5000	1	SC	GD	AV	9.0	6.0	0.1	15.0
RESOURCE MGMT.		3000	1	SC	GD	AV	5.4	3.6	0.0	9.0
INTER PROC. COMM.		1000	1	SC	GD	AV	1.8	1.2	0.0	3.0
FAULT MGMT.		1000	1	SC	GD	AV	1.8	1.2	0.0	3.0
MPAC UNIQUE		16700	1	SC	GD	AV	30.1	19.9	0.2	50.1
MPAC UNIQUE	2200		1	SC	GD	AV	39.6	26.2	0.2	66.0
SDP UNIQUE	1800		1	SC	GD	AV	32.4	21.4	0.2	54.0
NIU UNIQUE	1800		1	SC	GD	AV	32.4	21.4	0.2	54.0
EDP UNIQUE	1800		1	SC	GD	AV	32.4	21.4	0.2	54.0
TOTALS:	7600	40900					210.4	139.1	1.2	350.7

S U M M A R Y   C H A R T

AREA	NEW (SLOC)	COTS (SLOC)	REL.	CRIT.	PROJECT PROF.	DVPMENT PROF.	EARLY	PROCESS	PRODUCT	TOTAL
NOS	39600						799.2	384.8	4.0	1188.0
OS	7600	40900					210.4	139.1	1.2	350.7
ABA RTE	41500						771.0	469.9	4.2	1245.0
STANDARD SERVICES	93100						1811.6	957.7	23.7	2793.0
DMS SYSTEM MANAGEMENT	20700						433.4	181.2	6.4	621.0
DATA STORAGE & RETRIEVAL	26000	50000					629.6	289.0	11.5	930.0
USE	223500						4395.0	2147.5	162.5	6705.0
USE CONTINUED	144000	170000					3295.5	1373.5	161.0	4830.0
OMA	42000						882.0	336.0	42.0	1260.0
TOTALS:	638000	260900					13227.6	6278.7	416.4	19922.7


505.0
378.7
252.5
126.2
0
0
4.1
8.1
12.2